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Geopolymer Concrete a Sustainable Building Materials for Rural Housing

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Abstract

Housing is a basic human need. The house is not just shelter to protect from environmental conditions; it also becomes an instrument for social communication and supports a way of life. In present scenario speed, quality and economy of construction are the core issues of housing. Central and state governments are implementing various schemes and programmes for rural poor in construction of house. Out of the total cost of house construction, building materials contribute to about 70 percent in developing countries like India. Hence, there is an urgent need for promotion and adoption of alternative building materials and environmentally friendly cost effective construction technologies.Geopolymer cement concrete is a non-portland cement based sustainable concretes synthesized using industrial by products like ground granulated blast furnace slag, flyash, metakaolin, etc. and alkaline activator solution. It is one of revolutionary development related to novel material as an alternative to Portland cement. The mechanical properties of geopolymer concrete can be optimised by appropriate selection of raw materials, correct mix and design process to suit a particular application. The type of application of geopolymeric materials is determined by the chemical structure in terms of the atomic ratio Si: Al in the polysialate. This paper is an attempt to focus on promotion of new building materials for rural housing. Also it will demonstrate the feasibility of producing building products such as bricks, hollow blocks, building blocks etc. using geopolymer concrete. These sustainable building products will lead to reduce in carbon footprint. Geopolymer concrete has considerable potential to be used as a construction material in rural housing.

Keywords: *Building material; Geopolymer concrete; Hollow block; Rural housing.*

1. INTRODUCTION

Rapid urbanization, explosion of population and rural-urban migration has led to a substantial housing shortage. According to the Ministry of Rural Development study, the total rural housing shortage is 43.67 million dwelling units (2011). Housing, besides being a very valuable asset, has much wider economic, cultural, social and personal significance. With the current rates of urban development and the inability of housing delivery systems to cope with the need in India, the housing crisis is likely to increase in the future.The housing industry in India is the second largest employment generator, next to the agriculture sector. Portland cement and Construction industry is a major consumer of natural resources like rock, minerals, potable water and fossil fuel. The increasing demand for environmental friendly building material has been the main reason for sustainable development and cost effective housing construction.

Geopolymer technology is one of revolutionary development related to novel material like nano material as an alternative to Portland cement. The development of inorganic alumino–silicate polymer, called geopolymer, synthesized from materials of geological origin or by-product materials that are rich in silicon and aluminium is an effort in this direction. Several research and development efforts are in progress to address these issues. The mechanical properties of geopolymer concrete can be optimised by appropriate selection of raw materials, correct mix and design process to suit a particular application.

Geopolymer concretes can be made predominantly from industrial waste materials, such as fly ash, ground granulated blast furnace slag, rice husk ash, red mud and other materials which are rich in aluminium and silicon species that are soluble in highly alkaline solutions. The dissolved species undergo poly-condensation to produce materials with desirable mechanical properties. While pozzolanic cement generally depend on the presence of calcium, inorganic polymers do not utilize the formation of calcium silica hydrates for matrix formation and strength. These structural differences give geopolymer concretes certain advantages, such as an earlier strength gain compared with conventional cement binders. It has been found that inorganic polymers are stable materials with certain

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physical and chemical properties. In many cases, geopolymer concretes outperform Portland cement concretes with respect to compressive strength as well as acid resistance and fire resistance. Also, geopolymer concretes are cost competitive with general purpose cement concrete. For these reasons this emerging technology is gaining sufficient commercial interest around the globe.

2. LITERATURE REVIEW

2.1 Flyash Based Geopolymer Concrete

The term geopolymer was first applied by Joseph Davidovits to alkali alumino silicate binders formed by the alkali silicate activation of alumino silicate nano materials in 1978. Palomo *et al.* had made considerable research on flyash based geopolymer concrete and found that it is well suited to the precast application, because when thermally cured at 85 ^{o}C, mechanical strengths with values in the 60 MPa range were obtained in just 5 hours. They concluded that the silicon - aluminium ratio of the material almost doubled when the activator used was sodium hydroxide and sodium silicate. Hardjito *et al*. studied low calcium fly ash based geopolymer concrete and they found that higher concentration of sodium hydroxide solution resulted in a higher compressive strength of geopolymer concrete. It was reported that higher the sodium silicate - to - sodium hydroxide liquid ratio, resulted in higher compressive strength of geopolymer concrete. Rangan studied low calcium flyash based geopolymer concrete and obtained a compressive strength of 60 MPa when cured at 60 ^{o}C in an oven for 24 hrs. Data for the design of mixture proportion was also discussed. The elastic properties of hardened geopolymer concrete were found to be similar to the case of Portland cement concrete. He also studied long term properties and concluded that flyash based geopolymer concrete has excellent resistance to sulphate attack, good acid resistance and very little drying shrinkage. Daniel L. Y. Kong *et al.* compared the behaviour of low calcium flyash geopolymer and ordinary Portland cement under elevated temperatures upto 800 ^{o}C and concluded that the low calcium flyash based geopolymer concrete has superior temperature resistance. Ana *et al.* compared the mechanical strength, modulus of elasticity, bond strength and shrinkage of thermally cured alkali activated flyash concrete and ordinary Portland cement concrete and concluded that alkali activated flyash is a material with very promising cementitious features. Miranda *et al.* concluded that chloride free activated flyash mortars were found to passivate steel reinforcement as speedily and effectively as Portland cement mortars, giving no cause to fear that corrosion may limit the durability of reinforced concrete structures built with these new types of activated flyash cement.

2.2 Metakaolin Based Geopolymer Concrete

Palomo *et al.* studied thermally cured, metakaolin based geopolymer mortars made out of fine aggregate, metakaolin, sodium hydroxide and sodium silicate solution and found that the resultant material had good stability up to 270 days when submerged in aggressive liquids of various types. Elimbi *et al.* studied the most convenient calcining temperature of kaolinite clays in view of producing metakaolin based geopolymer cements. The setting time of geopolymer cement pastes produced from the clay fractions calcined at 450 ^{o}C was very long, about 21 days at the ambient atmosphere of the laboratory. For the clay fractions calcined between 500 and 700 ^{o}C, the setting time of geopolymer cement pastes reduced with increasing temperature and varied between 130 and 140 minutes. Above 700 ^{o}C the setting time began to increase. The linear shrinkage of the hardened geopolymer cement samples aged between 21 and 28 days attained its lowest value around 700 ^{o}C. Above 700 ^{o}C, the linear shrinkage began to increase. The compressive strength of the hardened geopolymer cement paste samples was between 11.9 and 36.4 MPa: it increased with samples from the clay fractions calcined between 500 and 700 ^{o}C but dropped above 700 ^{o}C.They concluded that the most convenient temperature for the calcination of kaolinite clays in view of producing geopolymer cement is around 700 ^{o}C.

De Silva *et al.* investigated the early reaction kinetics of metakaolin-sodium silicate-sodium hydroxide geopolymer systems. It was observed that the setting time of the geopolymer systems was mainly controlled by the alumina content. The setting time was found to be increased with increasing SiO_2 /Al_2O_3 ratio of the initial mixture. Up to a certain limit, the SiO_2 / Al_2O_3 was found to be responsible for observed high strength gains at later stages. Rovnanik studied metakaolin based geopolymer mortars and pointed out that milled metakaolin powders with high specific surface area showed faster setting characteristics, and higher compressive strength. He studied the effect of curing temperature and curing time on the compressive and flexural strengths of the alkali activated metakaolin material.He concluded that at an ambient and elevated temperature the material set practically within 4 hours at the latest and the treatment of fresh mixture at elevated temperature accelerated the strength development but the 28 days mechanical properties were deteriorated in comparison with the results obtained for mixtures that were treated at an ambient temperature.

2.3 Ground Granulated Blast Furnace Slag Geopolymer Concrete

Experiments conducted on the behaviour of Ground Granulated Blast furnace Slag (GGBS) based

geopolymer concrete found that it is suitable to make geopolymer concrete at ambient temperature. The workability varied with molar ratio. The 10M mix has a better workability, whereas the 7.5M mix used has good workability, the mix was able to fill the mould properly without affecting the quality of the mortar. Thus, most of the studies reported in literature on the synthesis of geopolymer concrete are requiring temperature and the present study aimed at developing geopolymer concrete at ambient temperature conditions.

2.4 Fire Behaviour

Normally, cement concrete has good property with respect to fire resistance. However, it is known that the residual strength of ordinary Portland cement concrete after firing between 800 °C to 1000 °C does not exceed 20-30 % normally because of dehydration and destruction of C-S-H and other crystalline hydrates, permeability, aggregate types etc. Fire introduces high temperature gradient and as a result, the hot layer tends separate and spall from the cooler interior layer of the body. In case of geopolymers posses good fire resistance at elevated temperature because of the existence of highly distributed nano-pores in the ceramic like microstructure that allows physically and chemically bonded water to migrate and evaporate with out damaging the alumina silicate network. During fire, several events such as evaporation of water adsorbed by N-A-S-H gel, formation of anhydrous products, crystallization of stable anhydrous phases and melting leading to destruction generally occurred. Kong *et al.* found that the residual strength of flyash based geopolymer pastes increased by 6 percent after exposure to 800 °C. The strength loss in flyash based geopolymer concrete at elevated temperatures is attributed to thermal mismatch between the geopolymer paste and aggregates. The strength of metakaolin based geopolymer pastes was reduced by 34 percent. Aggregate size larger than several nano meter resulted in good strength performance in both ambient and elevated temperature (800 °C).

3. RAW MATERIALS

Natural alumino-silicate minerals and industrial waste materials are used as important raw materials for geopolymerisation. The raw materials identified for synthesizing geopolymer concretes in this study are the following: Physical and chemical properties of raw materials are indicated in Table 1 & 2. Fly ash and GGBS were collected from Ennore thermal power plant, Chennai and Andhra Cements, Visakhapatnam respectively.

- Ground Granulated Blast Furnace Slag (GGBS)
- Flyash (ASTM Class F Flyash)
- Silica Fume
- Metakaolin
- Paper industry waste sludge

Table 1. Physical Properties of Raw Materials

Property	GGBS	Flyash	Metakao-lin	Silica fume
Specific gravity	2.91	2.24	3.15	2.09
Colour	ash colour	grey colour	light pink	light blue
Fineness	8% retained on 45um	9% retained on 45um	3% retained on 45µm	7% retained on 45µm
Loss of Ignition %	2.1	0.76	0.7	3.0
Bulk density kg/m3	1050 - 1375	560-860	-	130-430

Table 2. Chemical Properties of Raw Materials

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Ground granulated blast furnace slag (GGBS)	34.0	16.0	0.32	36.92	8.83
Fly Ash	49.1	26.4	9.3	1.4	1.4
Silica Fume	92.0	0.7	1.2	0.2	0.2
Metakaolin	52.1	41.0	4.32	0.07	0.19
Ground clay brick	54.83	19.05	6.0	9.39	1.77
Waste Paper ash	26.25	14.26	0.77	66.39	5.46

3.1 Alkali Activator Solution

Alkali activator solution used for initiating chemical reactions in geopolymer concrete mixtures in this study consisted of combination of sodium hydroxide and sodium silicate solution (activator 1) and sodium hydroxide solution alone (activator 2). Sodium hydroxide solution needed for activation was prepared to a concentration of 16 molar using sodium hydroxide pellets of 90% purity and distilled water. Sodium hydroxide solution was then mixed with sodium silicate solution in the ratio 1:2.5 to get alkali activator solution. In this study sodium silicate with SiO_2 to Na_2O ratio equal to 2 was used. Throughout the study alkali

activator solution was prepared 24 hrs prior to use and used within 36 hours time. Table 3 shows the physical and chemical properties of sodium silicate.

Table 3. Physical and chemical properties of sodium silicate

Chemical Formula	Na_2O SiO_2
Na_2O	15.9%
SiO_2	31.4%
H_2O	52.7%
Colour	Light yellow liquid (gel)
Boiling Point	102 ^{O}C for 40% aqueous solution
Molecular weight	184.04
Specific gravity	1.6

3.2 Aggregates

Normal fine river sand passing through 4.75 mm IS sieve and retained on 0.6 mm IS sieve was used as fine aggregate and locally available crushed granite stone aggregate of size 20 mm passing and retained on 10 mm was used as course aggregate in this study. Fine and course aggregates properties are indicated in Table 4.

Table 4. Properties of fine river sand and coarse aggregate

Property	Sand	Coarse Aggregate
Specific Gravity	2.6	2.7
Size	Passing through 4.75 mm sieve	Passing through 20 mm sieve and retained on 10mm sieve
Fineness modulus	2.5	6.4

4. EXPERIMENTAL STUDIES

In order to develop geopolymer concrete at ambient temperature, a range of trial mixes were prepared mainly with the three binder systems GGBS, flyash and metakaolin. In order to change the silica to alumina ratio of the binder material, which would affect the setting characteristics and strength characteristics of geopolymer concrete, silica fume was added in trial mixes with the binder material. Paper industry waste which is rich in lime and pure lime powder was also tried to improve the properties of trial mixes.

4.1 Casting of Specimens

Geopolymers are a new class of concrete construction materials and no standard mix design are available. Therefore, the formation of the geopolymer mixtures was done by trial and error considering workability and strength as parameters. In this study nearly 20 trial mixes were casted for the synthesis of the geopolymer concrete. The binder material and sand were mixed properly, hand mixing was done, in a water tight platform in dry state. The coarse aggregate was gently placed over it and was mixed thoroughly. Alkaline activator solution was added finally to the dry mixture. Mixing was done until a workable mixture was obtained. Concreting was done in three 100 mm size cube moulds while they were on a platform vibrator. Moulds were filled in three layers and in each layer vibrations were continued till uniform compaction. Table 5 shows the details of materials required for preparation of one cubic meter of Geopolymer concrete.

Table 5. Materials required for preparation of $1m^3$ Geopolymer concrete

Materials	Weight (kg)
GGBS	596
Sand	867
Aggregate	867
AAS	319

4.2 Curing Regime

All specimens were kept undisturbed at room temperature for 24 hours and were then removed from their moulds and kept at ambient temperature for curing till testing.

Table 6. Compressive strength of geopolymer concrete

Type of raw materials	7 day compressive strength (MPa)
GGBS geopolymer concrete	67
GGBS geopolymer concrete using activator 2	19
Flyashgeopolymer concrete using activator 1	5
Blend of Flyash and silica fume (80:20)geopolymer concrete using activator 1	3
Blend of Flyash silica fume and lime(72:18:10)geopolymer concrete using activator 1	15
Metakaolin based geopolymer concrete using activator 2	50
Blend of metakaolin and silica fume (60:40) based geopolymer concrete using activator 2	27
Blend of metakaolin and silica fume (50:50) based geopolymer concrete using activator 2	19
Blend of metakaolin and paper industry waste sludge (80:20) based geopolymer concrete using activator 2	50

5. SMALL WALL PANEL UNIT

Based on the literature review and the Indian social & economic system, it is decided to adopt a technology which is simple in adoption, labour oriented and easy to understand by the normal construction workers and which does not require sophisticated machine to use. In view of above a small wall panel system has been taken as a unit which will be called small wall panel unit as it will act as a wall panel and will be used as a block in construction. It will also be easy to handle by two persons on site. As per normal construction, the units can be placed as wall with the help of small columns on the functions. Accordingly the standard housing units can be designed for one and two room units for the rural people of the nation. Steel mould is fabricated using steel sheet with easily detachable nut and bolt connections Small hollow panel units of dimension 15 x 45 x 30 cm have been developed with 3.5 -6 cm concrete sections in the shape as given in the Fig.1 having two rectangular holes with larger size on one side, to ease in the production process. It will help to remove the mould to create hollow portions in the panel unit. It is designed on one side as male and other side as female part to give proper connectivity. The concrete mix was placed in moulds and was properly compacted. The hollow blocks were taken out from the moulds and were placed on open space for a week. After one week, when the specimens had attained sufficient strength for handling. Similarly a half unit has been conceived of size 15 x 22 x 30 cm having single rectangular hole and same size (Fig.2) of male and female parts to be used in the construction of wall to avoid the vertical joint and give a proper bond. The weight of the full unit is around 23 kg and that of half unit is nearly 12 kg which can easily be handled manually by two and one labour respectively.Also geopolymer concrete brick sample isshown in Fig.3

Fig. 1 : Small Hollow Panel Unit Full Size 15 x 45 x 30 cm

Fig. 2 : Small Hollow Panel Unit Half Size 15 x 22 x 30 cm

Fig. 3 :Geopolymer concrete brick

6. CONCLUSION

The following conclusions are drawn from the laboratory study: i) No heating was required for curing geopolymer concrete mix based on ground granulated blast furnace slag and metakaolin, ii) High early age compressive strength could be achieved with ambient temperature cured geopolymer concrete. Ambient temperature cured metakaolingeopolymer concrete performed well in terms of the mechanical properties, iii) Savings in energy costs, raw material cost as well as CO_2 emission was achieved, iv) Geopolymer concrete converts industrial wastes into environment friendly valuable building products like brick, hollow block, building block and has the potential to replace ordinary cement concrete in many application like precast units.

In present scenario, speed, quality and economy of construction are the core issues of housing.

Appropriate solution to provide affordable quality housing with socio-culturally acceptable and environment friendly characteristics continues to be a serious challenge for architects, builders, civil engineers and governments. Mass housing targets can be achieved by replacing the conventional methods of planning and executing of building operations based on individual needs. Rational use of building materials and resources are essential for rural housing. No single approach and solution is available can satisfy the community at large. However, low cost building system which can provide choice for community and also appropriate techniques to meet the situation. Adoption of any alternative technology on large scale needs a guaranteed market to function and this cannot be established unless the product is effective and economical.

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